How Does Kansas Assess Streams for Water Quality Impairments?

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KDHE

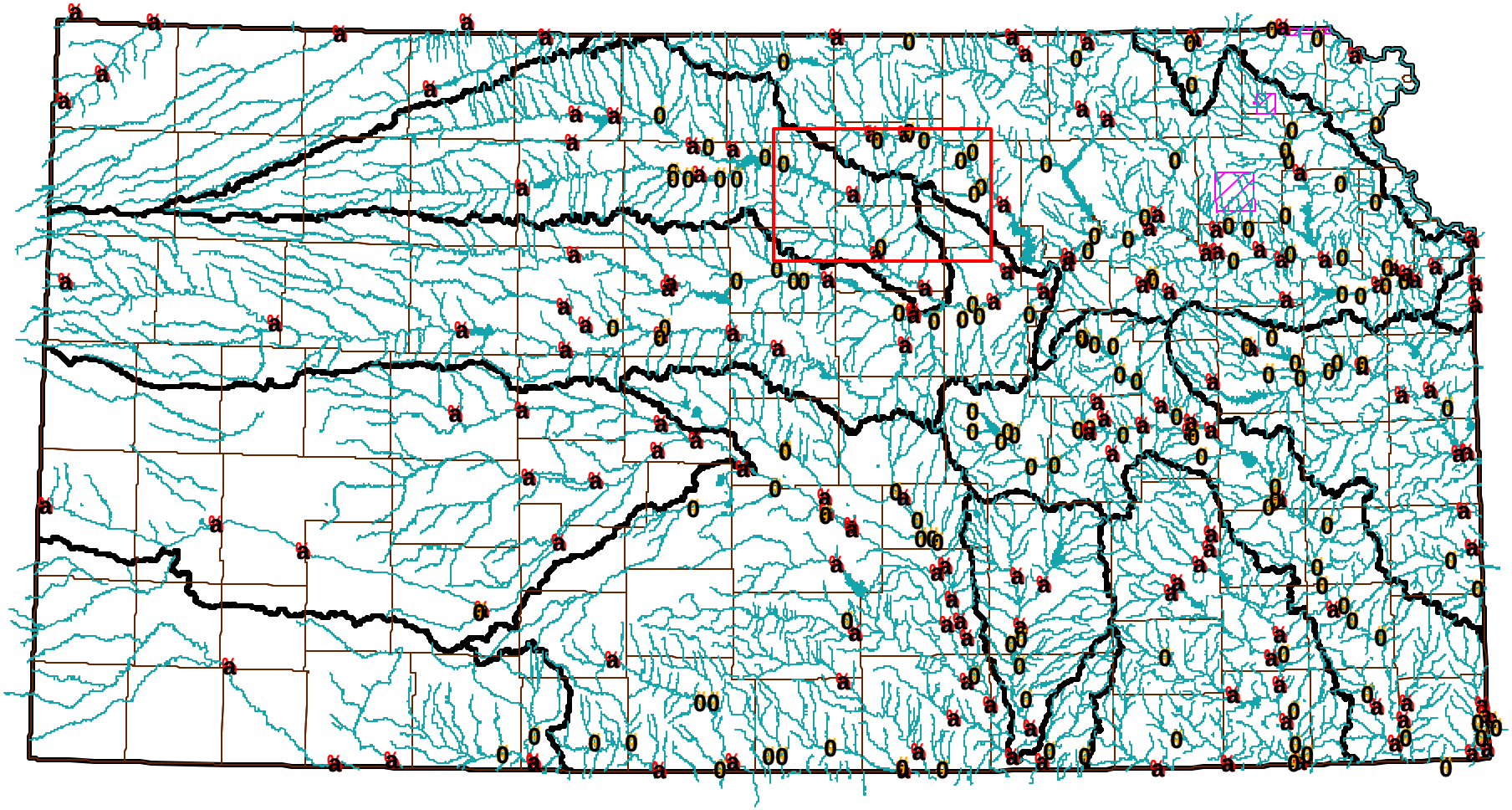
3 Parts of a Water Quality Standard

- Designated Use
- Criteria
- Anti-degradation

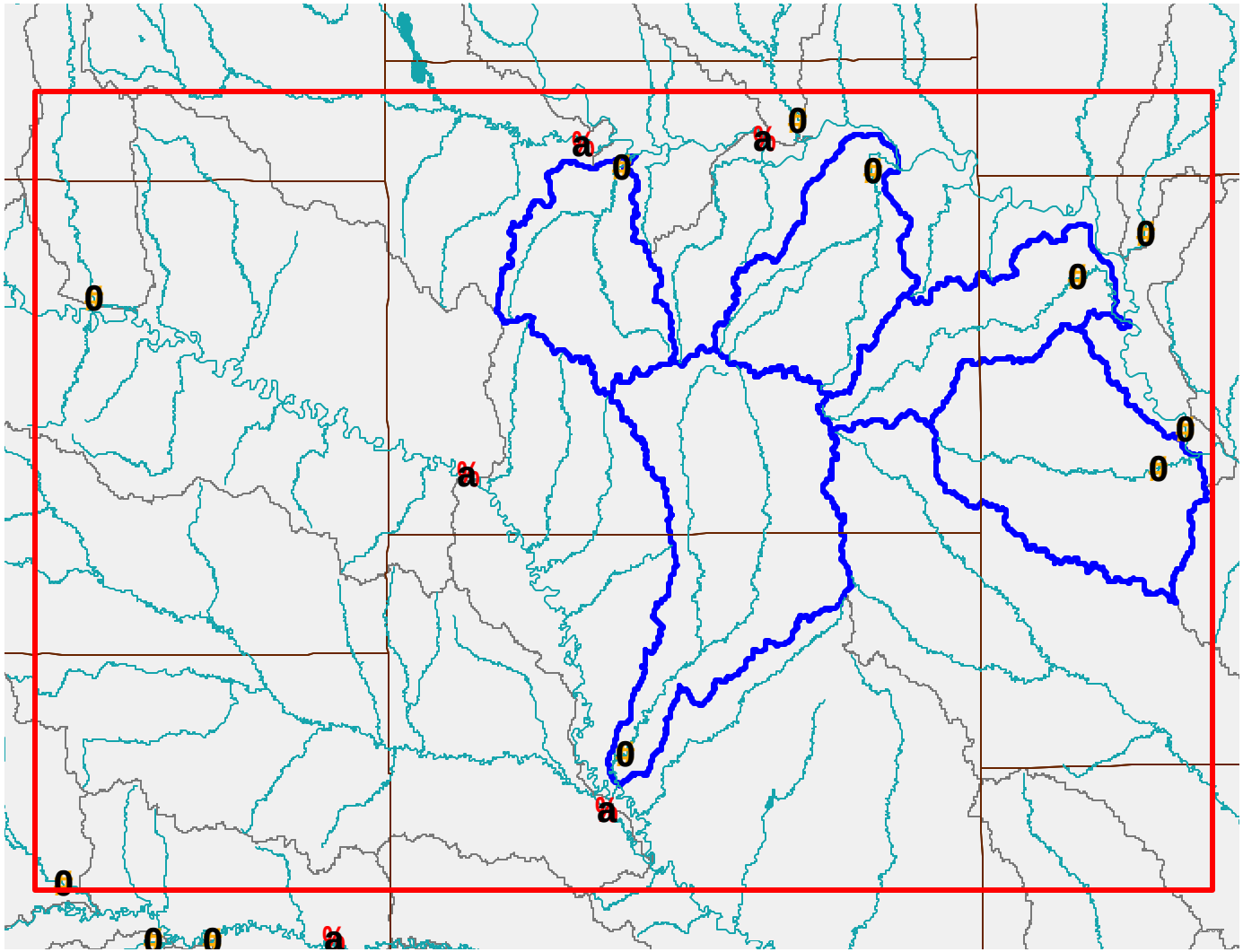
303(d) List - Background

- Surface Water Register
- Uses assigned to waters on Register (Designated Uses)
- Accompanying these Uses are Criteria (Numbers)
- Streams are monitored over time (Sampling)

Registered Waters and Monitoring Sites



Contributing Areas to Monitoring Sites



303(d) Background (Continued)

- From these samples, we assess waters for impairment to their designated uses via criteria
- If impairment is determined, waters are placed on list of impaired waters - 303(d) List
- TMDLs are developed for 303(d) Listed waters

Previously Used Impairment Determination Method

- > 10% of samples exceed criterion = impairment (Raw Score Method)

SITE A	
Sample #	Result
1	600
2	10
3	**9000**
4	**2200**
5	200
6	**1500**
7	10
8	700
9	10

SITE B	
Sample #	Result
1	400
2	225
3	**11000**
4	900
5	350
6	550
7	825
8	750
9	650
10	10
11	**9900**
12	200

SITE C	
Sample #	Result
1	100
2	300
3	**2600**
4	10
5	800
6	**2200**
7	425
8	**3500**
9	700
10	**1100**
11	10
12	250

TMDLs are written for 303(d) listed waters

- TMDLs can be expensive to develop and even more expensive to implement.
- It is important that the list be comprised of those waters that are truly water quality limited.

Assessment Errors

- Assessment runs the risk of two kinds of errors
  - 1. An assessment that lists unimpaired waters (type I error)
  - 2. An assessment that fails to list impaired waters (type II error)

Problem with Raw Score Method

- Based on the observed percentage of the distribution that exceeds a criterion
- For smaller sample sizes has high type I error (listing of unimpaired waters)

New Assessment Approach

- Binomial Method
- Based on an estimate of the true percentage of the distribution that exceeds the criterion
- Type I error rate is chosen as a matter of policy

Binomial Method

- Assessment guidelines = not more than 10% of samples exceed criterion
- Statistically the same as comparing the upper 90th percentile of the distribution to the criterion
- Never know the true 90th percentile with a finite number of samples with absolute certainty
- Confidence intervals can be used which allow us to capture uncertainty in our estimate on a percentile of the distribution

Cumulative Binomial Distribution

Using $$Bin(x;m,p)=\sum_{i=0}^{x}\binom{m}{i}p^{i}(1-p)^{m-i}$$

where $$\binom{m}{i}=\frac{m!}{i!(m-i)!}$$

and $$m!=m(m-1)(m-2)\cdots 1$$

$$\binom{12}{12}0.9^{12}(0.1)^{0}=0.282$$

$$\binom{12}{11}0.9^{11}(0.1)^{1}=0.377$$

$$\binom{12}{10}0.9^{10}(0.1)^{2}=0.230$$

From this, the minimum number of successes out of 12 trials to keep a water body off an impaired list is 10 (or, conversely, 2 failures out of 12 trials). This is the same as saying that 3 failures out of 12 trials will get a water body listed as impaired.

MS Excel function: BINOMDIST

Binomial Assessment Results

- To list a water body as impaired with as close to 90% confidence as possible

Sample Size *m*	Crit. # Exceed	Confid Level
12	3	0.889
13	3	0.866
14	3	0.842
15	4	0.944
16	4	0.932
17	4	0.917
18	4	0.902
19	4	0.885
20	4	0.867
21	5	0.948
22	5	0.938
23	5	0.927
24	5	0.915
25	5	0.902

Raw Score v. Binomial Method

SITE A	
Sample #	Result
1	600
2	10
3	**9000**
4	**2200**
5	200
6	**1500**
7	10
8	700
9	10

SITE B	
Sample #	Result
1	400
2	225
3	**11000**
4	900
5	350
6	550
7	825
8	750
9	650
10	10
11	**9900**
12	200

SITE C	
Sample #	Result
1	100
2	300
3	**2600**
4	10
5	800
6	**2200**
7	425
8	**3500**
9	700
10	**1100**
11	10
12	250

Sample Size	Crit. #	Confid Level
8	3	0.962
9	3	0.947
10	3	0.930
11	3	0.910
12	3	0.889
13	3	0.866
14	3	0.842
15	4	0.944
16	4	0.932

Binomial Method: Balancing Type I and II Errors

- Type I error is set
- Type II error Balances
  - Alpha for Type I error is 0.1 (not 0.05)
  - Minimum Sample Size Requirements
  - Historical Trend Check

Binomial Method with Additional Checks

SITE A	
Sample #	Result
1	600
2	10
3	**9000**
4	**2200**
5	200
6	**1500**
7	10
8	700
9	10

SITE B	
Sample #	Result
1	400
2	225
3	**11000**
4	900
5	350
6	550
7	825
8	750
9	650
10	10
11	**9900**
12	200

SITE C	
Sample #	Result
1	100
2	300
3	**2600**
4	10
5	800
6	**2200**
7	425
8	**3500**
9	700
10	**1100**
11	10
12	250

Sample Size	Crit. #	Confid Level
12	3	0.889
13	3	0.866
14	3	0.842
15	4	0.944
16	4	0.932
17	4	0.917

Parametric Method: Establishes Priority for TMDL Development

- Binomial Method does not take into account the magnitude of the excursions from the assessment criteria
- Once impairment is determined by Binomial Method, a Parametric Confidence Interval Method is applied to create a hierarchy for TMDL development

Parametric

- Normally Distributed Sample Data

$$LCL_{1-a,\,p} = \bar{x} + K_{a,\,p}\,s$$

where $\bar{x} = \sum_{i=1}^{m} \frac{x_i}{m}$ and $s = \sqrt{\sum_{i=1}^{m} \frac{(x_i - \bar{x})^2}{m-1}}$

and $K_{\text{"},p}$ is the one-sided normal tolerance limit factor for (")100% confidence and p(100)% coverage

- Lognormally Distributed Sample Data

the same method as described for normal data applies with exponentiation of the resulting limit.

$$LCL_{1-a,\,p} = \exp[\bar{y} + K_{a,\,p}\,s_y]$$

Adjustments for Censored Data

$$\bar{x} = \left(1 - \frac{m_0}{m}\right)\bar{x}'$$

$$s = \sqrt{\left(1 - \frac{m_0}{m}\right)(s') + \frac{m_0}{m}\left(1 - \frac{m_0 - 1}{m - 1}\right)(\bar{x}')^2}$$

Parametric Method

- Check for normally distributed data
- Transform data – Natural Log

SITE A		
Sample #	Result	LN (Result)
1	600	6.397
2	10	2.303
3	**9000**	**9.105**
4	**2200**	**7.696**
5	200	5.298
6	**1500**	**7.313**
7	10	2.303
8	700	6.551
9	10	2.303
Ryan-Joiner p-value	<0.01	>0.1
	LN Distrbn	EXP
Avg	5.47	
StDev	2.59	
LCL(90%)	7.25	**1411**

SITE B		
Sample #	Result	LN (Result)
1	400	5.991
2	225	5.416
3	**11000**	**9.306**
4	900	6.802
5	350	5.858
6	550	6.310
7	825	6.715
8	750	6.620
9	650	6.477
10	10	2.303
11	**9900**	**9.200**
12	200	5.298
p-value	<0.01	0.0639
	LN Distrbn	EXP
Avg	6.36	
StDev	1.81	
LCL(90%)	7.92	**2751**

SITE C		
Sample #	Result	LN (Result)
1	100	4.605
2	300	5.704
3	**2600**	**7.863**
4	10	2.303
5	800	6.685
6	**2200**	**7.696**
7	425	6.052
8	**3500**	**8.161**
9	700	6.551
10	**1100**	**7.003**
11	10	2.303
12	250	5.521
p-value	0.0403	>0.1
	LN Distrbn	EXP
Avg	5.87	
StDev	1.96	
LCL(90%)	7.56	**1922**

Conclusions

- Binomial approach used in determining whether impairments exist reduces the type I errors associated with previous assessment methods.
- Type II errors are reduced by a series of safeguard checks to ensure borderline, yet significant impairments are identified.
- Once listed, a Parametric Method ($LCL_{0.9,0.9}$) can be used to establish priority for TMDLs.

KDHE 303(d) and TMDL Web Sites

- 2004 303(d) Methodology and List
  - www.kdhe.state.ks.us/tmdl/basic.htm
- Kansas TMDLs
  - www.kdhe.state.ks.us/tmdl